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Overview of the Mars 2020 Parachute Risk Reduction Activity

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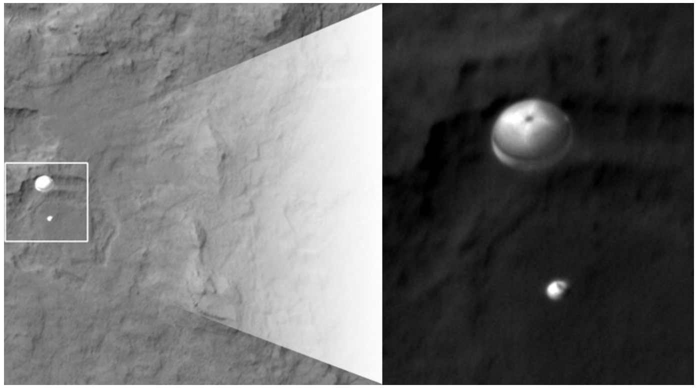
MARS 2020 PROJECT

MSL Parachute

- MSL successfully landed on the surface of Mars in August 2012 using a 21.35 m nominal diameter Disk-Gap-Band (DGB) parachute
  - Inflation occurred at a Mach number of approximately 1.7, a dynamic pressure of 474 Pa, and a peak load of approximately 35,000 lb
  - Flight limit load (the maximum load for which the parachute is designed to safely survive) for the parachute was 65,000 lb
    - Parachute only flew at approximately 50% of its design capability



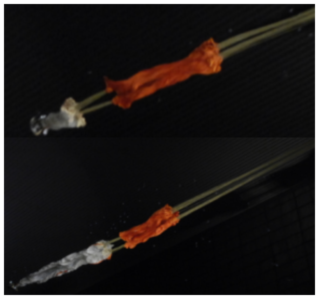
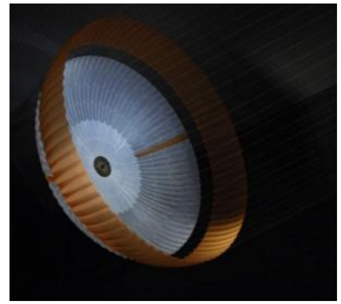
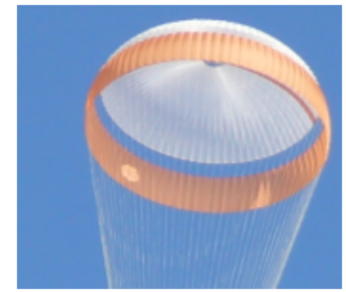
Credit: NASA/JPL-Caltech/Univ. of Arizona

- One of the biggest risks in the MSL entry, descent, and landing process was surviving the inflation of the largest supersonic parachute ever flown
  - Previously, the largest supersonic DGB was a 19.7 m nominal diameter DGB, which survived inflation, but had re-contact with the deployment bag

19.7 m DGB in flight

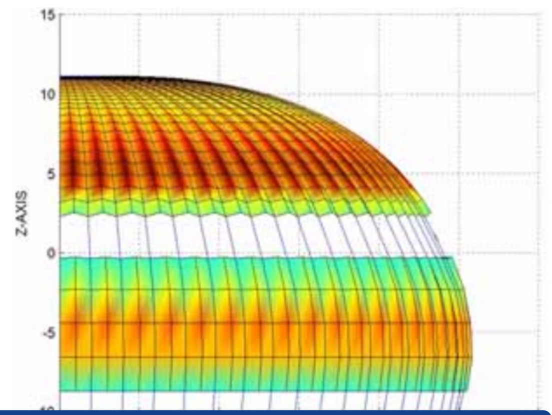
- A systematic approach to qualify the parachute and retire risk was developed and titled the Five Pillars

MSL Parachute System Qualification

Pillar 1: Mortar Deployment	Pillar 2: Canopy Inflation	Pillar 3: Inflation Strength	Pillar 4: Supersonic Performance	Pillar 5: Subsonic Performance
				
Parameters of Interest: • Deployment bag design • Line stretch mechanics • Packing methodology • Bag strip mechanics • Deployment bag retention **Test Parameters:** • Mortar ejection in low speed trailing flow (bounding) • Parachute/mortar design **Qual Method:** • Mortar ejection in low speed trailing flow (bounding) • Parachute/mortar design	**Parameters of Interest:** • Canopy inflation dynamics • Parachute design • Flow field **Test Parameters:** • Canopy inflation dynamics • Parachute design • Flow field **Qual Method:** • Similarity to PEPP and BLDT high altitude supersonic parachute deployments • Flight experience of Viking, MPF, MER, and Phoenix	**Parameters of Interest:** • Flight Limit Load on chute • Cyclic load on parachute to represent “area oscillation” re-pressurizations (3@81kip, 4@75kip, 3@65kip) **Test Parameters:** • Dynamic pressure • Parachute design **Qual Method:** • Dynamic pressure • Parachute design • Analysis	**Parameters of Interest:** • Parachute configuration • Drag coefficients • Mach efficiency curve • Stability coefficients • Area oscillations **Test Parameters:** • Mach number • Flow velocity & density • Parachute design **Qual Method:** • Similarity to PEPP and BLDT high altitude supersonic parachute deployments • Flight data • CFD and subscale supersonic wind tunnel tests to verify similarity	**Parameters of Interest:** • Parachute configuration • Drag coefficients • Mach efficiency curve • Stability coefficients **Test Parameters:** • Flow velocity • Parachute design **Qual Method:** • Sea level subsonic testing in the NFAC wind tunnel • Aerial drop testing and flight data from the Phoenix program

MSL Inflation Strength Qualification

- Structural Analysis
  - Structural margins were calculated at the flight limit load (65,000 lb) using hand calcs (in the lines) and CALA analyses (in the canopy)
    - CALA is a legacy parachute stress analysis code
    - Assumed uniform pressure distribution in fully inflated state
  - **Analyses all showed positive margin across the board**



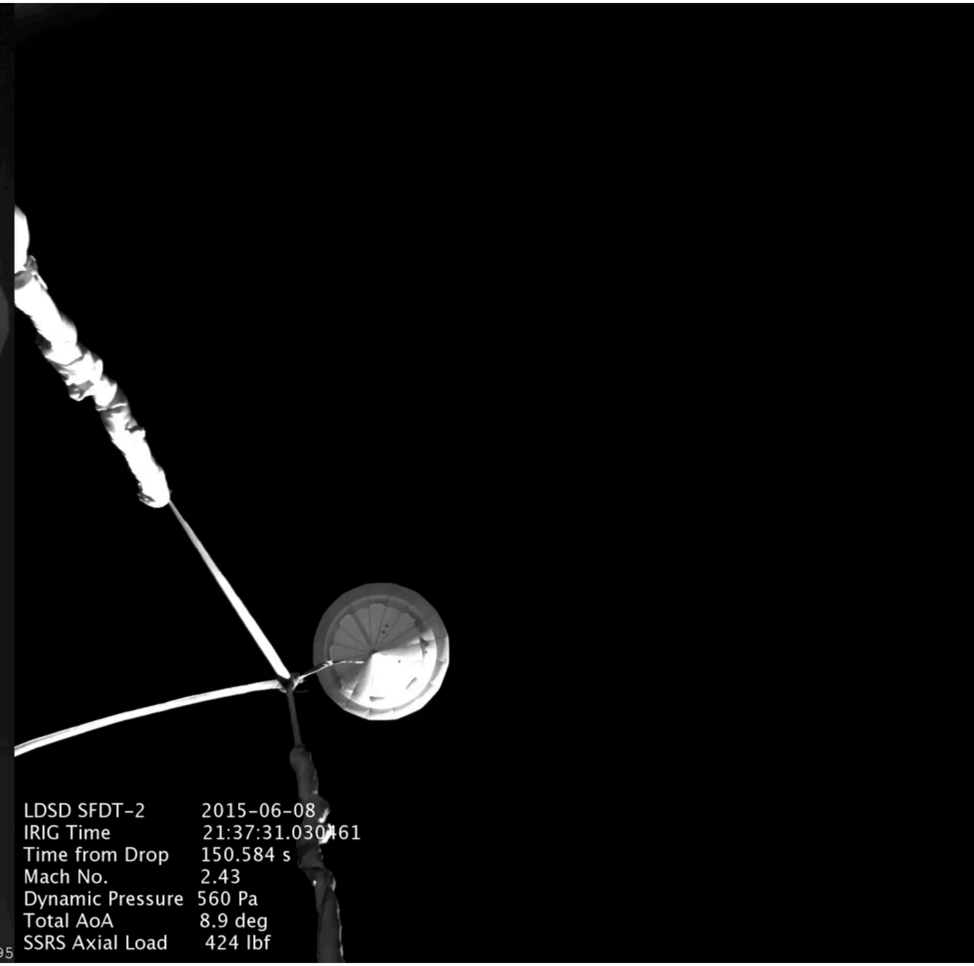
Parachute risk sufficiently low for flight!

- Sequential sleeve deployed inflations at decreasing loads to verify robustness to area oscillations
- The rationale for the sufficiency of a subsonic test was the following:
  - Inflation at Mars is infinite mass, so peak load occurs at full inflation
  - Inflation in a wind tunnel is infinite mass and peak load occurs at full inflation (although inflation occurs an order of magnitude slower)
- **The parachute assembly exhibited no detrimental wear or damage as a result of the mortar deployed or sleeve deployed inflations**

Change in Risk

- How can a parachute that was qualified and worked at Mars suddenly have higher risk ten years later?
  - The M2020 mission is built-to-print, so there are no gross changes to the entry configuration or mass
  - The parachute deployment conditions for Mars 2020 are similar to MSL
- First, the Low Density Supersonic Decelerator (LDSD) project fundamentally changed our view on the assumptions inherent in Pillar 3 (Inflation Strength)
  - LDSD followed a very similar inflation strength verification method as MSL with unexpected results
- Second, a historical review of supersonic DGBs indicated that the MSL parachute may have had the least amount of margin of any DGB flown at both Earth and Mars
  - Parachutes are not easily analyzed, so a relatively simple analytical method was employed to compare parachutes across generations in an apples-to-apples way
- The combination of these revelations has caused the Mars 2020 Project to pursue additional risk reduction activities to buy down the risk on the parachute system
  - To clarify, the risks for Mars 2020 are *different* than MSL, despite the EDL system being nearly identical, due to knowledge acquired in the time between MSL and Mars 2020

LDSD SFDT-1 and SFDT-2



LDSD Implications on Mars 2020

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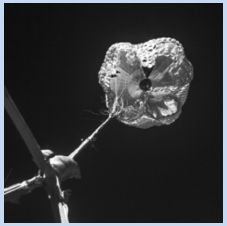
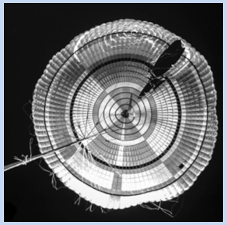
Parachute Failure

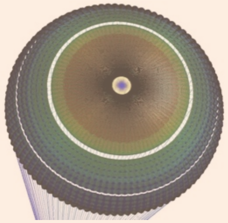


- SFDT-1 failed at 9000 lb (11% FLL)
  - Stresses beyond ultimate clearly occurred significantly before full inflation

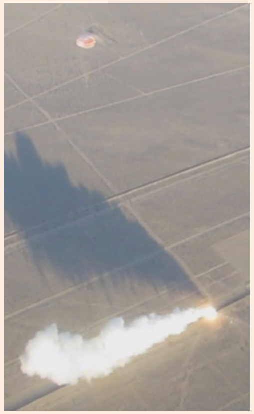


- SFDT-2 failed at 79,000 lb (99% FLL)
  - FLL should be the load at which the parachute can *safely* survive inflation, not its ultimate capability

MSL-Like Verification



- Disksail analytically showed positive margins to a load of 80,000 lb
- Ringsail analytically showed positive margins to a load of 166,000 lb
  - Higher load was analyzed to try to account for inflation dynamics and asymmetry
- Rocket sled testing of the two chutes to failure indicated:
  - Different failures modes than in supersonic flight
  - More capability in the canopy than in supersonic flight



Implications for Mars 2020

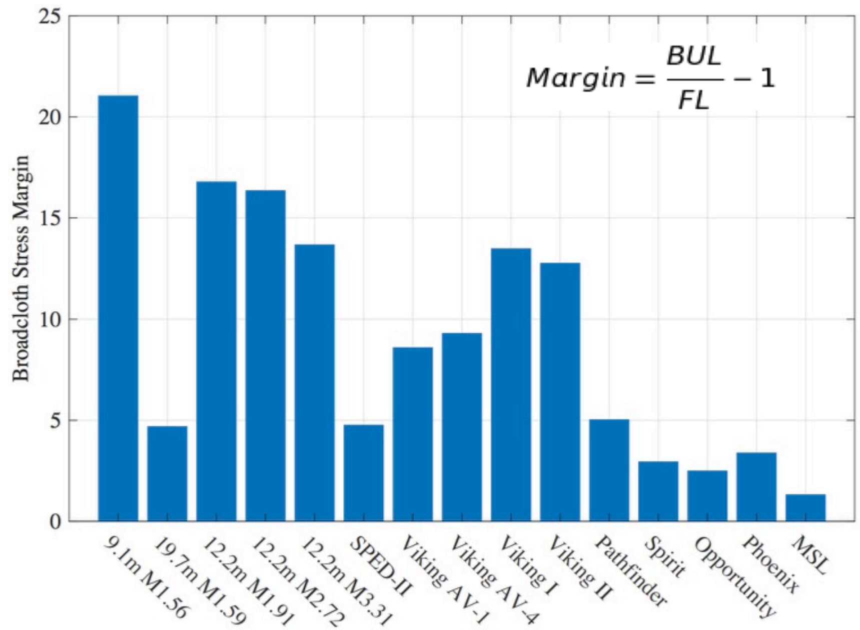
1. Stress does not necessarily correlate with parachute drag force. In other words, peak stress in the canopy does not necessarily occur at peak load (full inflation).
2. Our current quasi-static parachute analysis methods do not generate bounding stresses in the canopy, even if the applied load is significantly amplified, significantly decreasing the utility of margin analysis in some areas of the parachute.
3. Performing a subsonic overload test on a fully inflated parachute is not sufficient to determine that the parachute will survive a supersonic inflation at, or below, its flight limit load.

Historical Review of DGB Margins

- Supersonic DGBs were compared using simple pressure vessel theory to compare stresses against the theoretical ultimate capability of the parachute canopy (based on the material used)
  - Complex FEA analysis of parachutes are resource intensive to setup and run

- Margin, in this context, is quantified as the ratio of broadcloth ultimate load over the load actually flown at Mars / Earth
  - $BUL = \frac{Fr}{2tA}$

- Although simplistic, this comparison indicates that DGBs prior to MSL were much more over-designed for the loads at which they actually flew
  - DGBs have been very successful in the past, but is that because the materials used in those parachutes were incredibly strong for the parachute size and target drag loads?
  - Has getting "smarter" with our analyses really just eroded material capability that we actually need?



Mars 2020 Risk Reduction Plan

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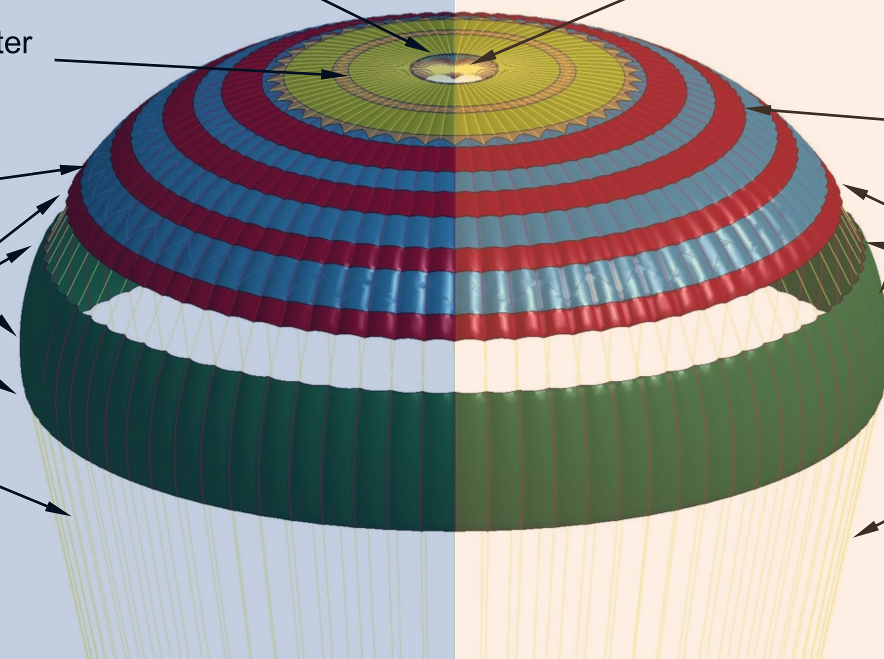
- Risk: Material margin for the large parachute may have been the lowest of any previous mission
- Mitigation: Design and fabricate two parachutes – a build-to-print parachute and a second parachute using stronger materials to increase the ultimate capability of the parachute assembly

- Risk: Subsonic overload testing of the parachute may not create sufficiently bounding stresses in the parachute assembly to reliably verify the structural integrity the parachute during a supersonic inflation
- Risk: Current state-of-the-art in parachute analyses due not necessary create sufficiently bounding stress to rely on margin analyses
- Mitigation: Perform supersonic inflations of full scale DGBs at appropriate Mach numbers and dynamic pressures to capture the asymmetry, pressure, and dynamics associated with a supersonic inflation
    - Repurpose the subsonic wind tunnel program as a workmanship verification prior to supersonic flight testing

Canopy Comparison



M2020 Built-to-Print

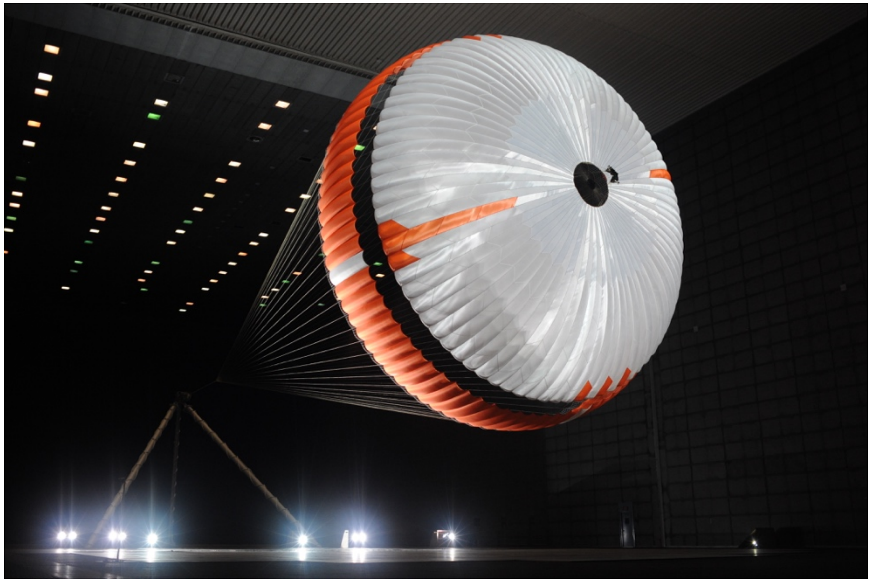
Mass Allocation:
Parachute Assembly: 58 kg
Parachute Decelerator System: 92 kg

M2020 Strengthened (Mars 2020 Baseline)

Mass Allocation:
Parachute Assembly: 88 kg
Parachute Decelerator System: 125 kg

Subsonic Workmanship Testing

- Workmanship testing occurred in the 80x120-ft test section at the NFAC wind tunnel at NASA Ames in June 2017



Pioneer Aerospace BTP Parachute
One mortar deployed inflation @ 76,000 lb

Airborne Systems Strengthened Parachute
One mortar deployed inflation @ 91,000 lb
Three sleeve deployed inflations @ 88,000 lb

- Workmanship testing was successful! No surprises in the parachute construction of either system
- Differences in load is still being investigated
  - Dynamic pressure for each deployment was approximately equal

Supersonic Inflation Testing

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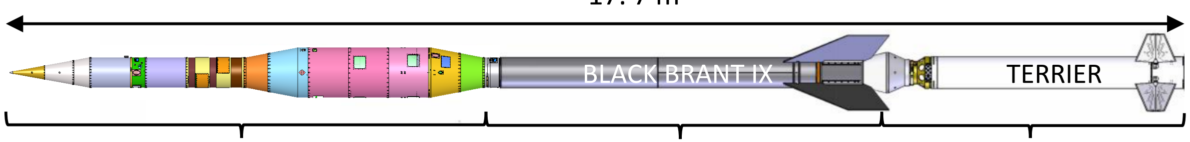
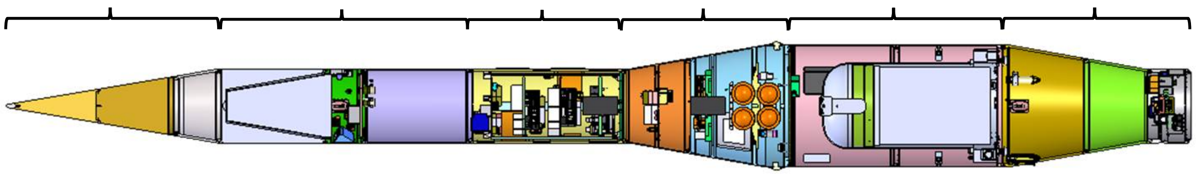
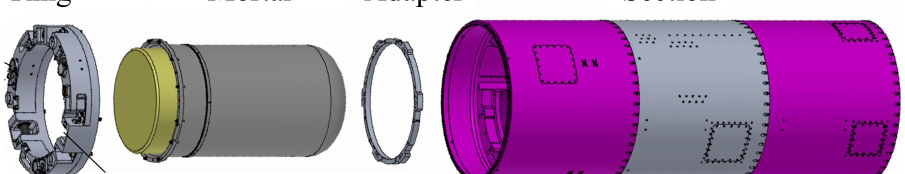
- The Advanced Supersonic Parachute Inflation Research and Experiments (ASPIRE) program was initiated to test full scale DGBs supersonically on a sounding rocket platform
  - Observe and verify supersonic inflation at relevant Mach numbers and bounding dynamic pressures
  - Recover the parachute for inspection







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for Public Release.

Supersonic Inflation Test Results

NASA

JPL
Jet Propulsion Laboratory
California Institute of Technology

NASA WALLOPS FLIGHT FACILITY GSFC
WFF

Advanced Supersonic Parachute Inflation Research and Experiments (ASPIRE)
Flight # 001
Date: 04 October 2017
Location: Wallops Flight Facility, Wallops Island, VA
Payload: 21.31 m D_0 Disk-Gap-Band Supersonic Parachute

ASPIRE

ZODIAC AEROSPACE

GENERAL DYNAMICS
Ordnance and Tactical Systems

Sounding Rocket Flights

- SR01
  - 04 October 2017
  - Build-to-Print parachute assembly
  - Target load of 35,000 lb
- SR02
  - 27 March 2018
  - Strengthened parachute assembly
  - Target load of 47,000 lb
- SR03
  - TBD July 2018
  - Strengthened parachute assembly
  - Target load of 70,000 lb